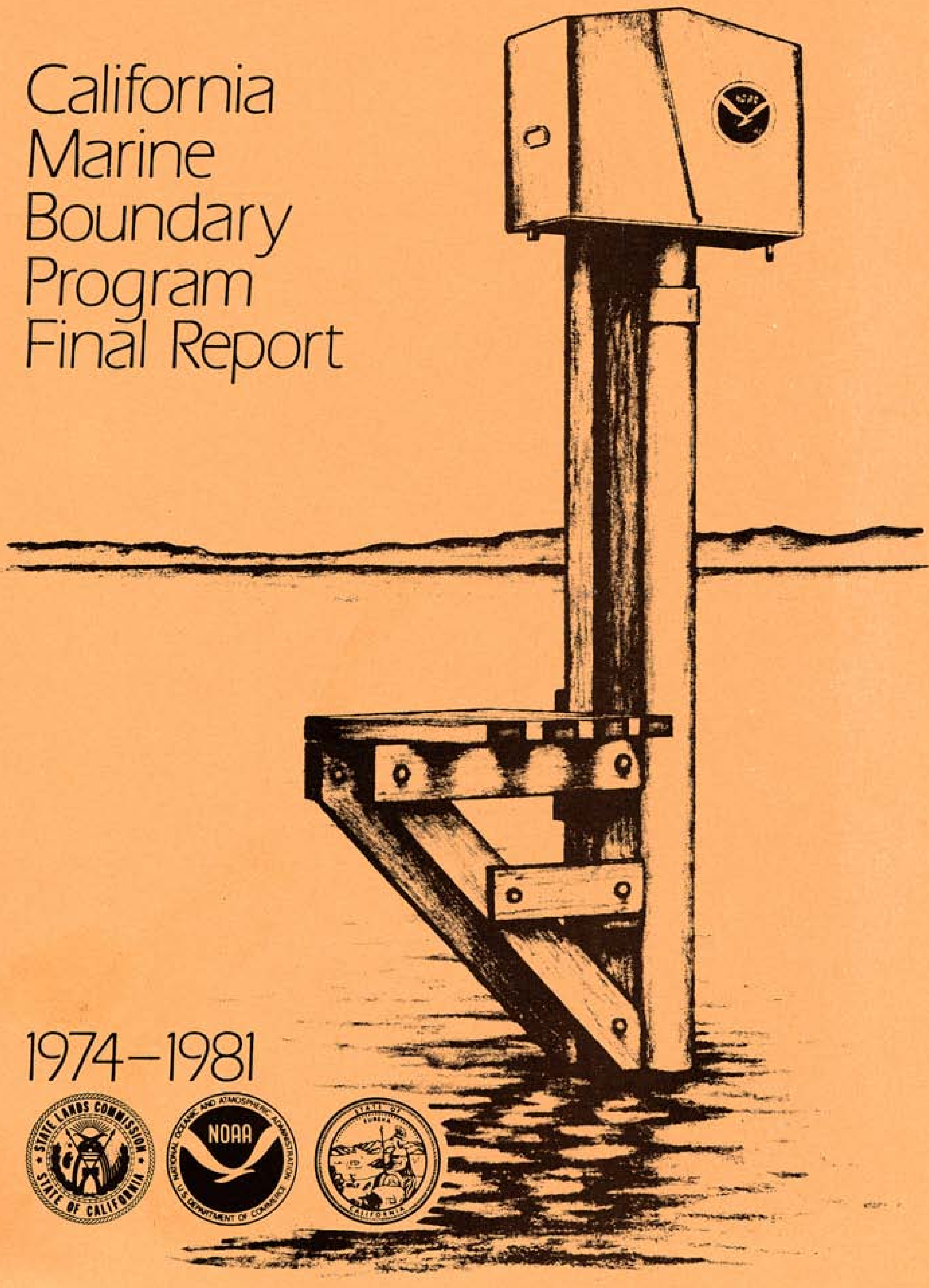
California Marine Boundary Program Final Report



1974–1981

STATE LANDS COMMISSION · STATE OF CALIFORNIA

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION · NOAA · U.S. DEPARTMENT OF COMMERCE

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Kathy Ross

State Lands Commission

State of California

CALIFORNIA MARINE BOUNDARY PROGRAM

FINAL REPORT

STATE OF CALIFORNIA/NATIONAL OCEAN SURVEY
COOPERATIVE PROGRAM

PREPARED BY THE

TIDES AND WATER LEVELS DIVISION
OFFICE OF OCEANOGRAPHY
NATIONAL OCEAN SURVEY

FOR THE

STATE LANDS COMMISSION
STATE OF CALIFORNIA

1982

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LIST OF ACRONYMS

ADR	Analog-to-Digital
CMBP	California Marine Boundary Program
COE	U.S. Army Corps of Engineers
CTP	California Tide Party
DHQ	Diurnal High Water Inequality
DLQ	Diurnal Low Water Inequality
ILS	Integrated Logistics Support
MHW	Mean High Water
MHHW	Mean Higher High Water
MLW	Mean Low Water
MLLW	Mean Lower Low Water
Mn	Mean Range
MSL	Mean Sea Level
MTL	Mean Tide Level
NGS	National Geodetic Survey
NGVCN	National Geodetic Vertical Control Network
NGVD	National Geodetic Vertical Datum
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Survey
NTON	National Tide Observation Network
PMC	Pacific Marine Center

NATIONAL OCEAN SURVEY/CALIFORNIA MARINE BOUNDARY PROGRAM

I. INTRODUCTION Prepared by A. K. Landsbergis and D. M. Martin

The main objective of the National Ocean Survey (NOS)/California Marine Boundary Program (CMBP) is to utilize tidal data obtained from the established tide stations to determine tidal datums of sufficient accuracy to delineate marine boundaries and support the NOS Nautical Charting Program. In addition to providing the surveyors with tidal bench marks from which boundaries can be delineated, it also provides information that enhances mapping of the coastal areas.

The NOS and its predecessor agencies have been making tide observations since 1834. The early tide observation programs focused on the needs of nautical charting. In later years, the need for determination of marine boundaries placed more emphasis on tidal programs for that specific purpose. To acquire the necessary tide data for establishing baselines for demarcating marine boundaries, the NOS operates three types of tide stations; primary, secondary, and tertiary. Briefly these can be described as follows:

The primary tide stations comprise a portion of the National Tide Observation Network (NTON). They are permanent installations where continuous tide observations are collected for a minimum of 19 years. Their purpose is to provide 19-year accepted values for datum computation, control of datum determination from short-term observations, and to monitor long-term sea level variations which affect datum computations. The data from these stations is also used to review and update the National Tidal Datum Epoch.

Secondary tide stations are required to obtain tidal data at intermediate locations within the NTON, and information about seasonal variations and general tidal characteristics within a particular bay or estuarine system.

Tertiary tide stations are short-term stations at which continuous observations are made for a minimum of 30 days. They provide a local datum and information concerning general tidal characteristics at intermediate points within the secondary network of stations.

In response to requests from state governments, marine boundary or tidal datum survey programs were developed for individual coastal states. The first cooperative cost-shared program was with the State of Florida in 1969, followed by New Jersey, California, South Carolina, Mississippi, and Louisiana.

II. BACKGROUND Prepared by A. K. Landsbergis and D. M. Martin

In March 1974, NOS entered into a cooperative agreement with the San Francisco District, U.S. Army Corps of Engineers (COE) to establish 15 secondary tide stations in South San Francisco to determine tidal datums to assist in regulating development activities. Prior to the termination of the COE agreement in March 1976, California State officials became interested in the cost-sharing marine boundary program because of pending litigations throughout the state. Subsequently, NOS and the State Lands Division signed an agreement in January 1976 for a 4-year program to collect tide data from as many tide stations as could be reasonably funded under the terms of an agreement which was to be terminated December 1979.

NOS provided the state with a detailed plan for tidal requirements for all the coastal and estuarine areas of California. At the beginning of the third year of the program, it was apparent that at the existing level of Federal/State funding, all the requirements could not be met by December 1979. NOS requested a list of priority areas from the state and in conjunction with NOS requirements to support hydrographic operations in California, a number of options were presented in June 1978. It was mutually agreed that the secondary network of stations would be completed in San Pablo Bay, Suisun Bay, and the Sacramento and San Joaquin Deltas. Secondary and tertiary station networks had already been completed for San Francisco Bay, Humboldt Bay, Tiajuana Estuary, and Moss Landing. By December 1979, all of the optional requirements of June 1978 were completed and approximately 50 percent of the original program plan were accomplished. The following is a summary of the proposed stations and those established during the program:

	Total Number of Proposed Tide Stations	Number of Stations Established at the End of Project	Number of Stations to be Established	Percentage Accomplished
Primary	4	2	2	50%
Secondary	114	80	34	70%
Tertiary	186	71	115	38%
Total	304	153	151	50%

III. FIELD ACQUISITION OF DATA Prepared by R. F. Edwing

A. Introduction

The tide party was the medium through which the CMBP Boundary was transformed from project instructions to an operational tidal observation network. The tide party, tasked with performing the field operations, was a mobile unit receiving technical direction and funding from Headquarters in Rockville, Maryland and logistical and operational support from the Pacific Marine Center (PMC) in Seattle, Washington. The tide party, by necessity, was responsible for much of its own administration, coordination, logistics, equipment maintenance, and transportation. Meshing those functions with the varied contingencies of running a field operation presented a challenge which required dedication, determination, and a team effort from all involved. The result was an efficient tidal observation network collecting valuable, high-quality tidal data.

B. California Tide Party (CTP)

At its inception in July 1975, the CTP was essentially a one-person field effort. At this time the program was a cooperative agreement between NOS and COE with input from the State of California. It required only a limited amount of tide stations. With the entrance of the state of California into the program in January 1976, the scope expanded and the CTP assumed the structure it would keep throughout the program. This consisted of:

Chief of Party (one) - NOAA Corps Officer
Oceanographer (one) - NOS civilian employee
Survey Technician (one) - NOS civilian employee
Student Engineering Aide (four) - State of California employees

The Chief of Party primarily managed the administrative duties and worked mostly at the field office. He was the main link in communications between the CTP, PMC, and Headquarters. His major responsibilities were:

1. supervision of employees,
2. maintenance of lines of communications,
3. approval and forwarding of project data,
4. periodic reports,
5. finances,
6. logistics coordination, and
7. securing installation permission from property owners.

The Chief of Party position was a NOAA Corps Officer assignment throughout the program with the exception of the final 4 months when it was filled by an oceanographer.

July 1975 through November 1975 - Lt. Gary Adair, NOAA
November 1975 through April 1979 - Lt. Roger A. Morris, NOAA
April 1979 through November 1979 - Lt. (jg) Fain McGough, NOAA
December 1979 through March 1980 - Richard F. Edwing

The Oceanographer primarily managed the field operations. He functioned as technical advisor and liaison between Headquarters and the field office. He also provided continuity to the program during changes in Party Chief. His major responsibilities were:

1. scheduling and field supervision of:
   a. tide station installations,
   b. tide station inspections,
   c. tide station removals, and
   d. emergency maintenance;
2. completion of all operational documentation;
3. Analog-to-Digital (ADR) and analog roll scan for data defects;
4. maintenance and repair of spare tide gages;
5. training of new employees; and
6. monitoring logistic and equipment maintenance requirements.

The Oceanographer position was a permanent duty assignment for an NOS civilian employee detailed from Headquarters in Rockville, Maryland.

January 1976 through May 1978 - Mark W. Allen
May 1978 through March 1980 - Richard F. Edwing

The Survey Technician functioned primarily as an aide to the Oceanographer by acting as a crew leader and assisting with most of the duties listed above. The Survey Technician required good knowledge and experience with tide gages, differential leveling, support equipment, and general construction. Often the Survey Technician functioned as a jack-of-all-trades, performing minor maintenance and troubleshooting on the boats, vehicles, support equipment, etc. The Survey Technician position was a temporary slot and, for the most part, was renewable. This enabled the same employee to be kept on continuously for a good part of the program. At times there were two Survey Technicians attached to the CTP to compensate for a heavy schedule or temporary difficulties in hiring Student Engineering Aides.

The Student Engineering Aides provided assistance in establishing, maintaining, and removing tide stations. Local individuals with an engineering or science background were generally hired to facilitate their training. They were hired on 9-month temporary appointments. The more experience and skills Student Engineering Aides accrued, the more duties and responsibilities were entrusted to them.

All of the positions required dedication, determination, and teamwork to accomplish the program's objectives. The travel was extensive, often requiring up to 3-week long road trips to establish, maintain, or remove distant tide stations. Overtime was mandatory due to the distances involved and quantity of work to be accomplished. Hardships such as adverse weather, equipment failure, strenuous physical labor, and disagreeable surroundings were not uncommon. However, the satisfaction gained from the successful completion of project goals and the enjoyment derived from working outdoors throughout coastal and estuarine California, more than made up for the rigors.

C. Station Components/Instrumentation

All secondary and tertiary tide stations established by the CTP consisted of the following components:

1. analog-to-digital (ADR) tide gage, float, and floatwire;
2. stilling well;
3. support structure(s);
4. tide staff; and
5. tidal bench mark network.

The ADR tide gages used in the program were procured from two manufacturers, Fischer & Porter and Leupold & Stevens. Both types of gages, in general, employ identical principles of operation and were thus used interchangeably throughout the program. Each has a maximum range of 50 feet and records water level heights to hundredths of a foot, mechanically converting angular positions of a rotating shaft with a float, wire, and float reel assembly into binary coded (8, 4, 2, 1) decimal output. This information is recorded on a 16 channel foil-backed data tape being punched every 6 minutes. The data sampling interval of 6 minutes is controlled by a solid-state timer. The gages are powered by a 7.5 volt battery and are protected from the elements by weatherproof security covers.

The Fischer & Porter models 1550 and 1551 are identical except for their exterior housing. A more detailed description of the Fischer & Porter ADR may be found in "Fischer & Porter - Instruction Bulletin (Number 35-1550C) for Type 1550 and 1551 Punched Tape Level Recorder (Spring Counterbalance Type) Design Level 'C'."

A more detailed description of the Leupold & Stevens ADR may be found in Leupold & Stevens "Instructions: Stevens Digital Recorder Model 7031, 7032."

The stilling well is a vertical tube with a relatively small opening (orifice) in the bottom. It is used in a tide gage installation to dampen high frequency waves while freely admitting the tide to actuate a float which, in turn, operates the tide gage. It extends to a water depth well below, if possible, that of the lowest tide. A schedule 40, 4-inch diameter PVC pipe was used by the CTP in most cases. Occasionally, however, stilling wells already established by other agencies, such as U.S. Geological Survey, Bureau of Land Management, COE, and California Department of Water Resources were available and were utilized by the CTP. These stilling wells varied in size and type.

The tide staff is a nonrecording tide gage consisting of a vertical graduated staff from which the height of the tide can be read directly. It is graduated in feet and tenths of a foot with the length varying, dependent upon type and manufacturer. Because of marine fouling, the tide staff is usually made of or coated with an easily cleaned surface such as fiberglass or vitrified enamel. It is used as a reference standard for comparative observations and is related to local bench marks by differential levels.

At each station, a network of at least five tidal bench marks was established through recovery of historical bench marks and/or the setting of new bench marks. The standard tidal bench mark of the NOS, to which the tide staff and tidal datums are referred, is a brass disk 3-5/8 inches in diameter.

The gas purged pressure gage, commonly known as a "bubbler", is an analog type gage which was occasionally used as a backup gage or for reconnaissance. It is a portable pressure-recording instrument that produces a continuous strip chart record of water level changes. The underwater part of the gage consists of a small orifice chamber attached to a gas supply tube. The shore end of the tubing is connected to the gas system (pressure regulation mechanism and nitrogen gas storage tank) and to the transducer (temperature-compensated pressure bellows) and a strip chart recorder. The Metercraft Model 7601 was used by the CTP. Additional information on this tide gage is contained in Metercraft's "Instruction: Dry Purged Pressure Recording Tide Gauge by Metercraft."

D. Station Installation

The CTP established tide stations at sites selected by Headquarters in Rockville, Maryland, and issued in annual Project Instructions. Prospective station sites were either historical, defined as having had previous tidal measurements and tidal bench marks established, or nonhistorical. The locations selected by Headquarters were as geographically specific as possible, but were dependent upon features detailed on the best available NOS nautical charts, U.S. Geological Survey Quadrangles, and/or NOS aerial photography used to plan the station sites. In some cases where no support structures were apparent from the office information, a general area was provided for the CTP to locate a site. At certain locations a Metercraft Bubbler was required to be installed for a minimum of 3 days to determine whether tidal characteristics changed enough in that area to warrant an ADR tide station installation.

The first step in establishing a tide station was a thorough reconnaissance of the prospective site. A reconnaissance involved traveling to the site and:

1. Recovering all historical tidal bench marks (if any) and any other bench marks which were set in the area by other agencies. Any National Geodetic Vertical Control Network (NGVCN) bench marks within a 1-mile radius of the site also were recovered. If additional bench marks were needed, prospective sites were designated.

2. Locating a suitable support structure with sufficient water depth and accessibility. If no support structure was available then the selection of a suitable site for the construction of a support structure was necessary. In both cases a detailed list of materials and equipment needed to install the tide station was compiled.

3. Obtaining permission from the property owner for installation of the tide station.

4. Locating a potential tide observer.

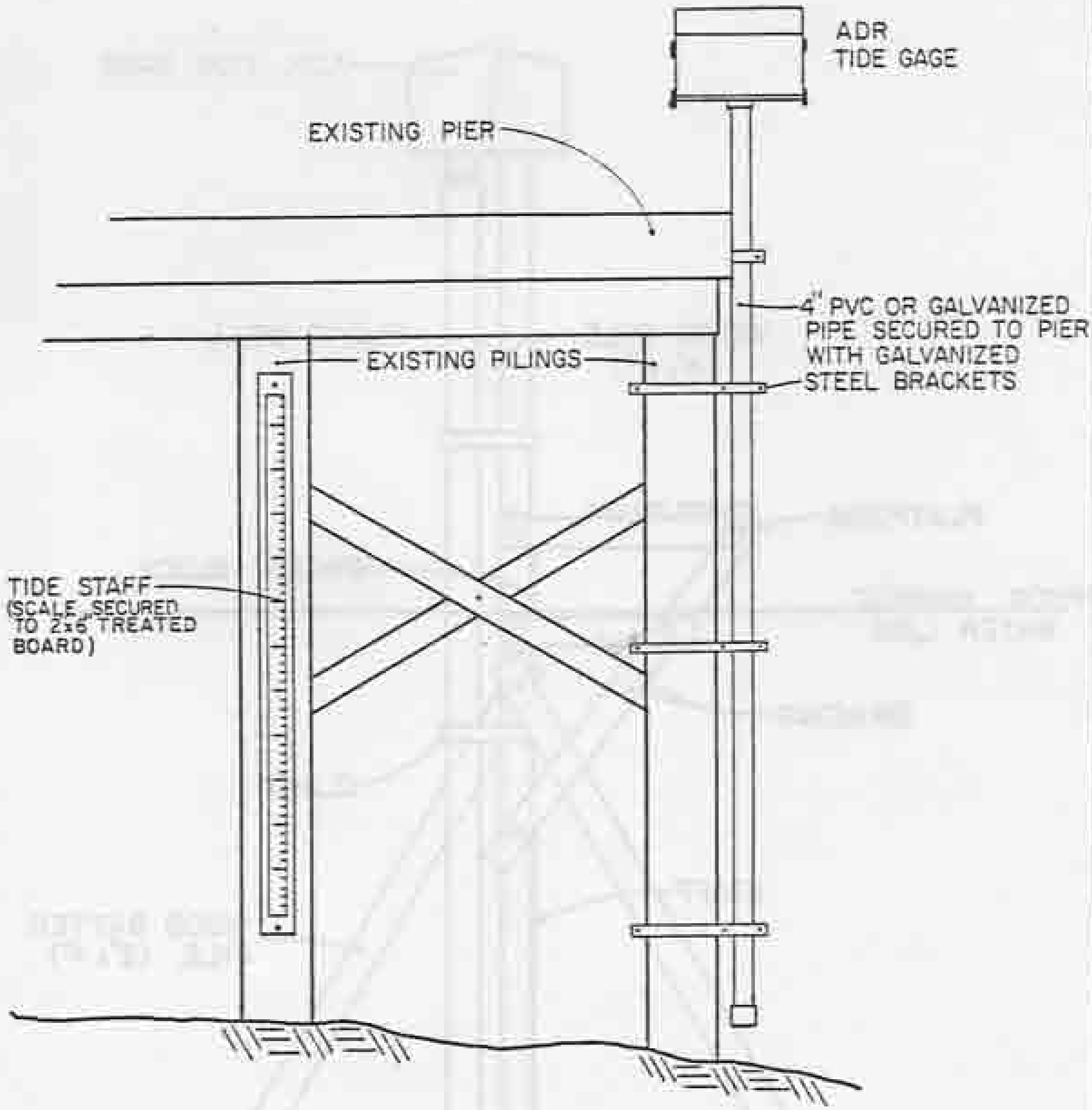
The next step was the actual establishment of the tide station. A typical installation consisted of the stilling well being attached by various types of brackets and/or stainless steel bands to a pile. Piles were utilized from piers (figure 1), fenders, channel markers, bridges, railroad trestles, or were sometimes freestanding. If a pile or a previously established stilling well (from another agency) or some other suitable structure was not available then a support structure had to be constructed. The support structures constructed were either freestanding piles (figure 2) jetted into the bottom with bracing batters or a three- to four-corner platform (figures 3 and 4).

The tide staff was fastened to a support backing, usually a 2- by 6-foot treated plank, and was preferably attached to a different pile than the stilling well in order to isolate any settlement problems. The tide staff was placed so that it covered the full range of tide, was easily visible to the tide observer, and accessible for cleaning and surveying.

Most of the tide stations were installed at lower low waters to allow the stilling wells and staffs to be secured to the support structures as far down as possible. In some cases, this was not feasible and scuba diving was required to properly make the installation.

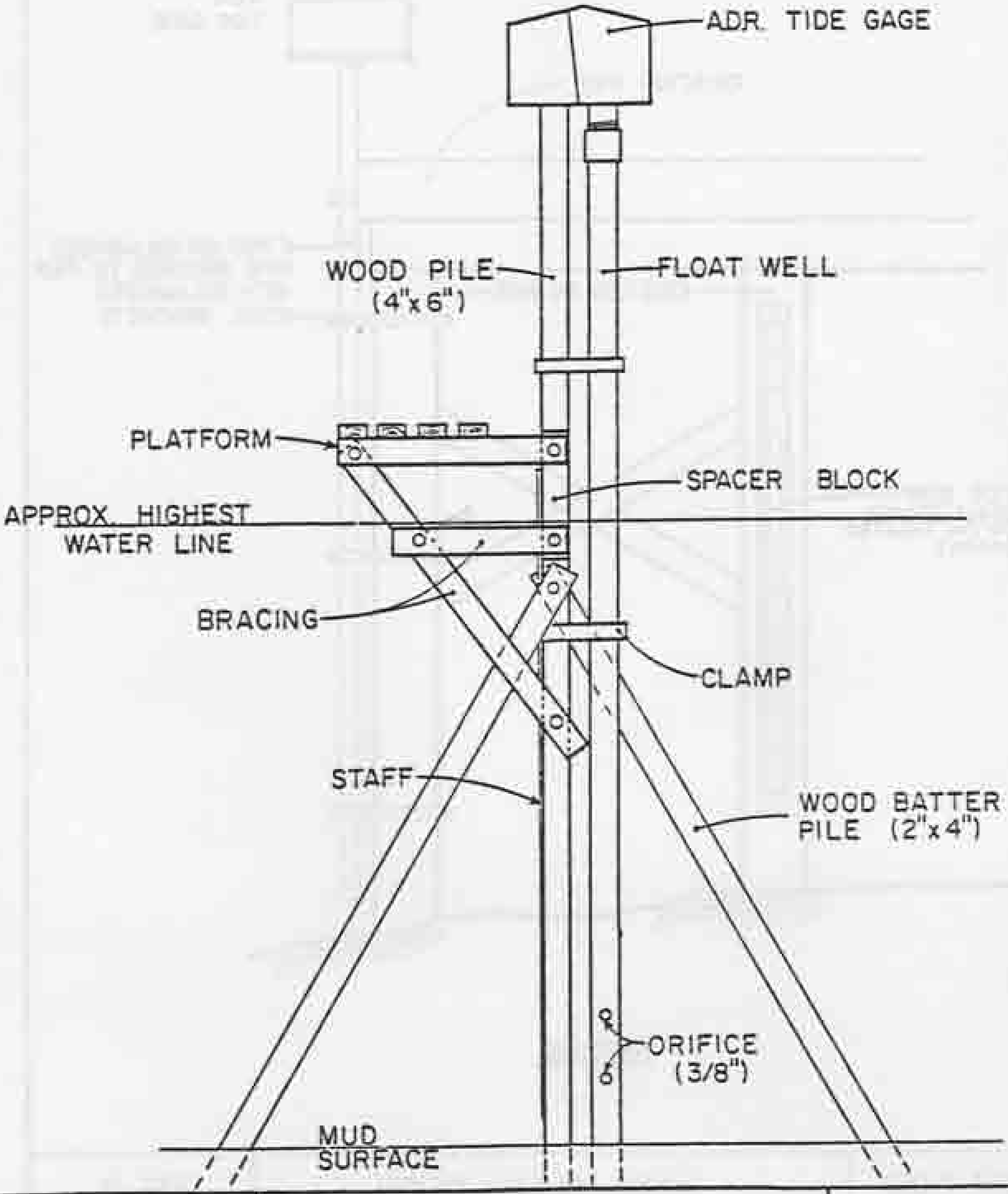
At some of the San Diego County Lagoon tide stations a Metercraft Bubbler was installed in addition to the ADR tide gage as a backup gage. In addition the analog records were used to examine short-term water level fluctuations, wave groups, freshwater runoff variations, and possible wind and rainfall events that are unique to these small systems. The Metercrafts were installed and operated in accordance with the "User's Guide for the Gas-Purged Pressure Recording (Bubbler) Tide Gage."

Bench marks at each tide station were established in accordance with the "User's Guide for the Establishment of Tidal Bench Marks and Leveling Requirements for Tide Stations (User's Guide)." A network of at least five tidal

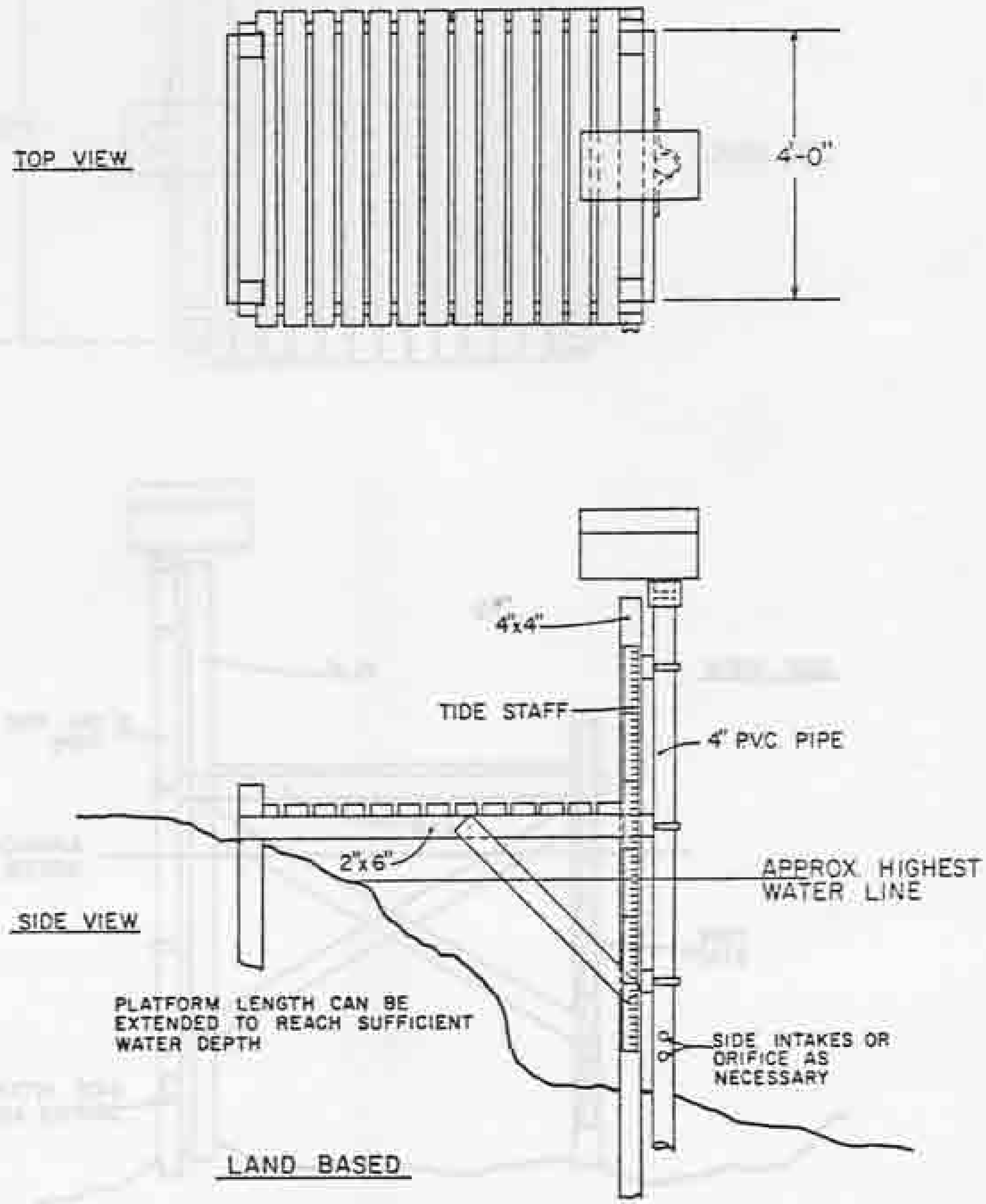


SECTION

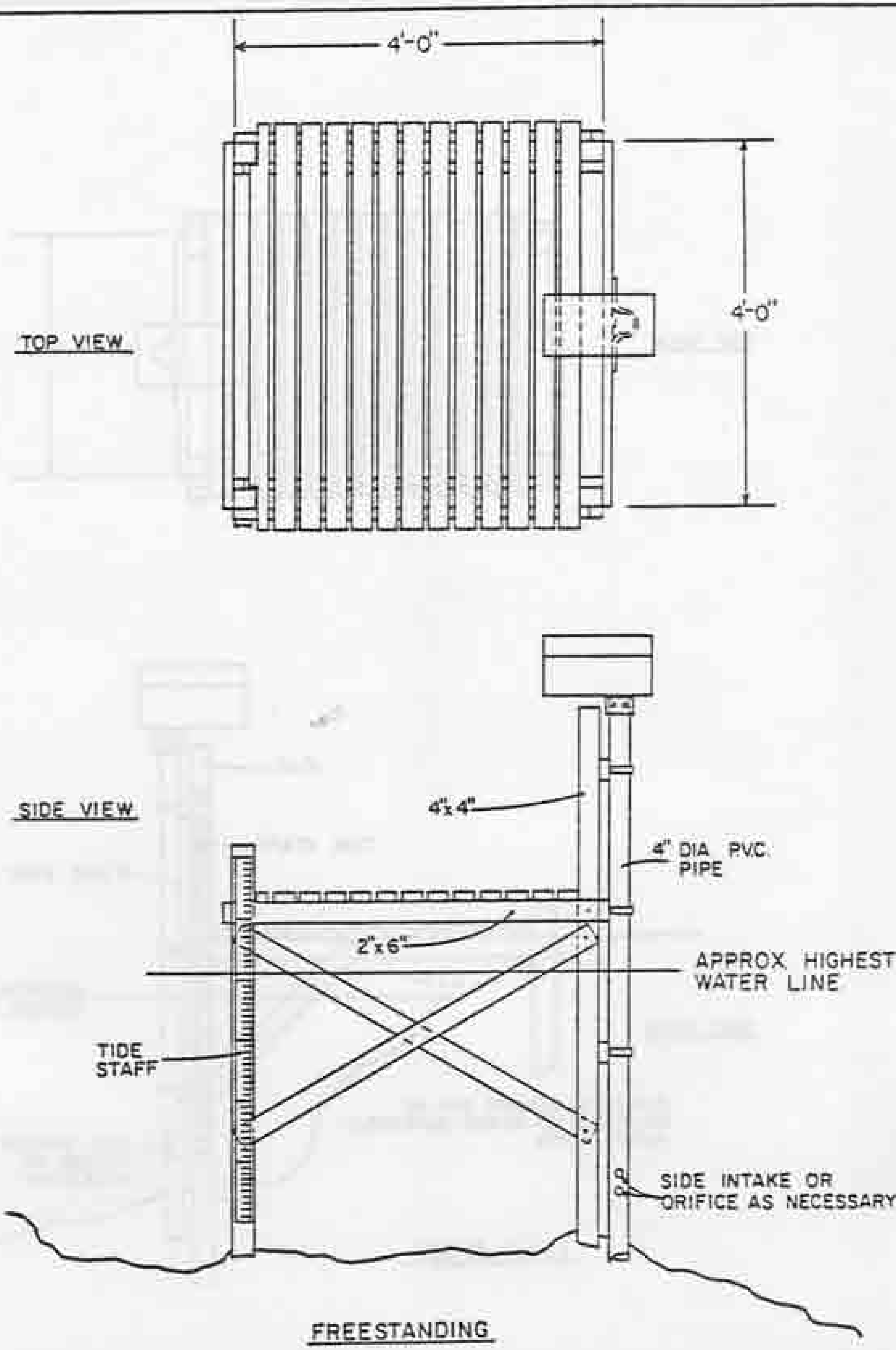
NOAA/NOS	PIER INSTALLATION	FIG. 1
DATE: 1/81	CONCEPTUAL SKETCH	DRAWN BY: RJM



NOAA/NOS	FREESTANDING PILE INSTALLATION	FIG. 2
DATE: 1/81	CONCEPTUAL SKETCH	DRAWN BY: RJM



NOAA/NOS	PLATFORM GAGE INSTALLATION	FIG. 3
DATE 5/81	CONCEPTUAL SKETCH	DRAWN BY: RJM



NOAA/NOS	PLATFORM GAGE INSTALLATION	FIG. 4
DATE: 5/81	CONCEPTUAL SKETCH	DRAWN BY: RJM

bench marks were established at each tide station by recovery and/or the setting of new bench marks. The types of bench marks set, at least 200 feet apart, were bedrock, deep rod, and monument (large man-made structures). They were standard NOS brass survey disks stamped with the last four digits of the respective tide station number, a designating letter, and the year.

All differential leveling between the tide staff, tidal bench marks, and the NGVCN bench marks was performed to the data quality standards (frequency, accuracy, collimation tests, observing routine, closing error) in accordance with:

"User's Guide for the Establishment of Tidal Bench Marks and Leveling Requirements for Tide Stations," by Lt. Cdr. A. Nicholas Bodnar, Jr., NOAA Tidal Requirements and Acquisition Branch, NOS, December 8, 1977.

"Classification Standards of Accuracy, and General Specification of Geodetic Control Surveys," prepared by Federal Geodetic Control Committee, NOS, February 1974, reprint May 1978.

"Specifications to Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys," by Federal Geodetic Control Committee, John O. Phillips, Chairman, NOS, July 1975, reprint May 1978.

Differential levels to all five bench marks were run at each tide station upon installation. The instrumentation available were two Zeiss Ni_2 automatic levels. At secondary stations, Second order, Class I differential levels were run using the 3-meter Zeiss precise rod L12 with an invar scale and half-centimeter graduations. At tertiary stations, third order differential levels were run using the Metagrad Philadephia rods graduated in centimeters. Two Zeiss parallel-plate micrometers and sighting targets were available for water crossings.

The hiring and training of the tide observer was one of the most important aspects of the tide station installation. A competent, well-trained tide observer makes a significant difference in the quality of the tidal data produced by a tide station.

To document tide station installation and record data, a number of NOAA forms were used. They were:

1. Tide Station Report (NOAA Form 77-12),
2. Precise Leveling-Three Wire (NOAA Form 77-29),
3. Abstract of Precise Leveling (NOAA Form 76-183),
4. Leveling Record, Tide Station (NOAA Form 76-77),
5. Description of Bench Mark (NOAA Form 76-75),
6. Recovery Note, Bench Mark (NOAA Form 76-89),
7. Weekly Tide Station Report (NOAA Form 77-24), and
8. FAILog (NOAA Form 44-6).

In addition to these forms, photographs, a large-scale map section indicating the station location, a sketch of the bench marks, tide gage, and staff locations, and a description of how to reach the tide station from a major landmark, were forwarded to Rockville, Maryland, as a tide station package.

E. Tide Station Operation and Maintenance

Once a tide station was installed it was incorporated into a regular cycle of monitoring and maintenance. Monitoring was accomplished in two steps. First was a monthly roll scan by the CTP oceanographer. This was performed during the first part of each month when all the tide rolls had been forwarded to the CTP by the tide observers via mail. All tide rolls were mailed in special cannisters by the observer and were sent certified or registered mail to help prevent their being lost. Upon receipt by the CTP the rolls were scanned for data defects such as mechanical, time, and/or observer problems. The problems were noted for corrective action by the CTP and as a processing aid for the Tidal Analysis Branch in Rockville, Maryland. All but the most subtle problems were identified and remedied in a timely fashion by this first step.

The second step was performed by the Tidal Analysis Branch in Rockville. If additional problems were identified by the Tidal Analysis Branch in the course of processing a roll, the CTP was notified by telephone and a follow-up preliminary evaluation form.

Emergency repairs were performed on a tide station if either of the previous steps turned up a problem. In addition, the CTP was notified of problems by telephone and/or Weekly Report by the tide observer responsible for the tide station.

At tide stations of sufficient duration, semiannual inspections were performed. This would involve leveling to three bench marks, a visual inspection of the tide gage and the past week of punched data, contact with the tide observer, and if the ADR gage was a Leupold & Stevens, a torque test to measure the bearing friction. Torque tests were performed more frequently at tide stations susceptible to bearing deterioration, such as tide stations in areas of low tidal range and/or high salinity.

Annual inspections were performed at tide stations of sufficient duration. The annual inspection was identical to the semiannual inspection except that all five bench marks were leveled and their descriptions verified.

The removal of a tide station involved leveling to all five bench marks, removal of all equipment except the bench mark, and restoration of the site to its original condition, unless otherwise requested by the property owner. A tide station was removed only upon instructions from Headquarters in Rockville, Maryland.

F. Logistical Support

The CTP operated out of several locations in the San Francisco Bay region throughout the course of the program. At each location the CTP set up logistics along the same basic line.

At each location, an office area was set up to provide working space for administrative purposes and to serve as the communications center. A telephone recorder was used to record emergency calls and other messages. A shop area was set up to provide space for the storage of equipment and materials, equipment repairs, and fabrication of station components.

Vehicles assigned to the CTP consisted of a carryall and two utility trucks. The carryall was primarily used for leveling inspections and the trucks for station installation and removal.

Boats provided vital support to the CTP. Two 10-foot fiberglass Livingston Whalers with 10 hp outboard motors were easily transported on top of either truck. A 21-foot Glasspar runabout and a 24-foot flat-hulled Monark work boat were transported by trailer. All boats were employed in reconnaissance, maintenance, construction, and in the support of scuba diving operations.

The Monark was equipped with special gear to enable the tide party to set 4- by 6-inch treated redwood piles for freestanding support platforms (figure 2). An aluminum "A" frame fit into chocks on the Monark and was used in conjunction with a block and tackle, and a power winch. This equipment was used to hoist the pile and securely set it into position. Prior to placement, a 4-inch PVC floatwell with orifice and a tide staff was secured to the pile. These were correctly positioned from depth measurements taken during reconnaissance. A 1-inch PVC pipe was also attached to the pile by banding. This pipe ran the length of the pile and was connected to a gasoline-powered jet pump to a jet in the pile. After the main pile was set, 2- by 4-inch or 2- by 6-inch redwood batter piles were set by sledge hammer and/or jetting to provide support. Then a small platform and the tide gage were added.

Specialized equipment was also needed to install bench marks (figure 5a). For bedrock and monument marks (figure 5b), a gasoline-powered rock drill/hammer was used to drill the holes needed to mortar-in the bench marks (figure 5c). To install deep rod bench marks the following equipment and procedures were employed.

After a site was selected, and permission obtained, the local utility companies were contacted (if deemed necessary) to determine if any cables or pipes were located in the area. This was accomplished during reconnaissance. Installation was begun by digging a hole approximately 1-1/2 feet deep by 1 foot in diameter. A section of 5/8-inch diameter, 8-foot long galvanized steel rod (NOS is now using 9/16-inch diameter type 304 stainless steel rods in 4-foot sections) was held vertically in the center of the hole and pushed in as far as possible by hand. A gasoline-powered rock drill with a pipe tamper attachment elevated by a portable aluminum "A" frame (or by standing up on the side of a truck's utility body) was used to drive the rod down (figure 5d). Rods were connected to each other by couplers sealed with pipe joint compound. When the rod had been driven to refusal or 50 feet, the excess was cut off and the bench mark disk crimped on below grade, using a hydraulic hand pump. A short section of 4-inch PVC pipe was placed around the bench mark and a cement kickblock was poured around the pipe. A witness post was also installed if circumstances warranted it.

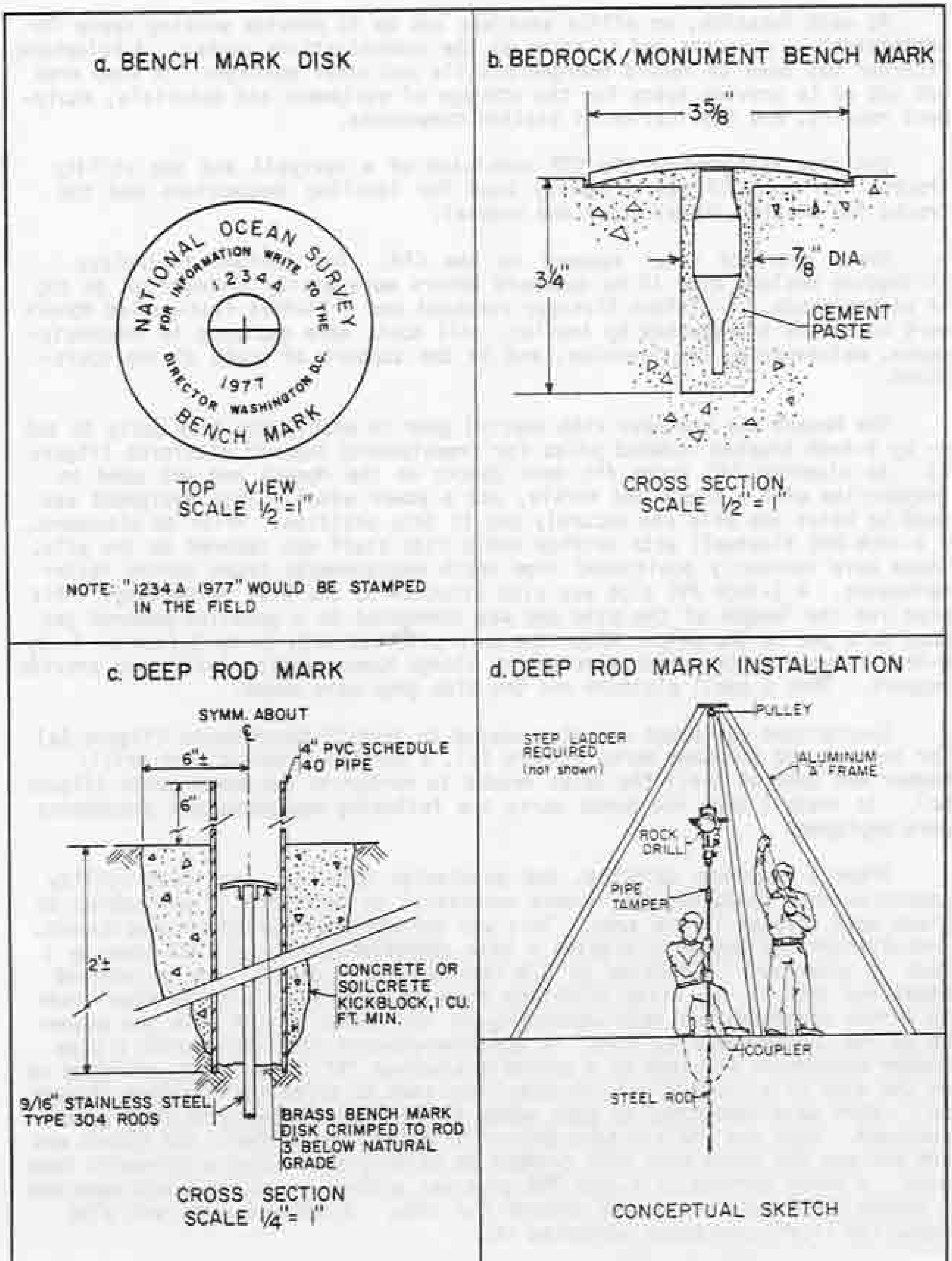


FIG. 5: ILLUSTRATION OF TYPICAL BENCH MARK, BEDROCK/MONUMENT BENCH MARK, DEEP ROD MARK AND INSTALLATION OF A DEEP ROD MARK

Scuba diving was performed by qualified members of the CTP. It greatly facilitated the installation, maintenance, and removal of most tide stations and was essential at many.

G. Operational Difficulties

Operational problems arise in any program and the CMBP experienced some throughout its course. The objective of pointing these problems out is to prevent them from recurring, if possible, or to have provisions made for them in future programs. None of the problems were insurmountable and were worked out, but they did impact the CTP in terms of time and money; and the CMBP in terms of lost data.

California is a large state and the CMBP had tide stations along the coast and in estuarine systems from the Mexican border up to Humboldt Bay, a distance of about 700 miles. Tide station locations were established as far inland as Sacramento and Stockton, about 75 miles from the Golden Gate. This was a very large area for a field party to cover. Most (approximately 75 percent) of the tide stations were in the San Francisco Bay/Delta area, and thus were within 2 to 3 hours drive of the base, but the farthest locations in the Tiajuana Estuary were a long day's drive. This made it difficult to respond to emergency repairs in as timely a fashion as was desired. It also tied up personnel and equipment for lengthy amounts of time to install, maintain, and remove the farther stations.

In covering such a large area a wide variety of environmental conditions were encountered. Tide station locations ranged from high energy open coast sites to low energy backwater areas. Stations were established in bays, harbors, lagoons, canals, marshes, rivers, sloughs, and almost every type of waterway possible. Each waterway type and its particular requirements had to be taken into consideration when designing an installation. The seasonal weather patterns also had to be taken into consideration at some of the locations. California has a rainy season, a period running approximately from November through April, when over 90 percent of the annual rainfall occurs.

Tide stations established in areas affected by heavy freshwater runoff were subject to damage by excessive currents, floating debris, or by actual flooding of the tide gage. In a few cases a slough's path would be altered and the tide station would be left dry or cut off from tidal influence. The "masking" of the tides by the freshwater runoff also made it difficult to identify certain problems, such as floatwell clogging, when performing the monthly roll scan.

These conditions were commonly encountered in areas subject to heavy runoff such as all the San Diego County Lagoon stations and many of the delta stations, particularly near the Sacramento area.

Equipment and instrumentation malfunctions impacted the CTP in terms of time, scheduling, and money. Certain vehicles, boats, and equipment were essential to particular operations , and if that support was unavailable, the operation had to be delayed. Tide gage breakdowns were top priority and required immediate response from the CTP. Malfunctions were unpredictable and depending upon the number and time of occurrence, impacted the CTP to varying degrees.

Analog-to-digital recorder tide gage malfunctions resulted from a variety of reasons. Defective parts, worn out parts, bad batteries, tide observer error, and external abuse (such as vandalism, being hit by boats, etc.) all contributed to ADR malfunctions. Both types of ADR gages had certain malfunctions which tended to occur more often than others. The Fischer & Porter had most of its malfunctions center around the punch block and tape advance mechanisms. The Leupold & Stevens malfunctions centered around the encoding input system which is discussed in more detail later. Both gages experienced timer malfunctions and at one point, a shipment of defective data tapes (the advance sprocket holes were improperly spaced) resulted in a plethora of malfunctions.

A major impact on the CTP occurred when the Leupold & Stevens "stepping" problem came to light and preventive maintenance measures were instituted in the early summer of 1978. Stepping in an ADR gage is defined as a continuous series of flat spots followed by a sudden rise or fall. In a Leupold & Stevens it was commonly caused by the encoding drum, bulkhead, and negator spring bearings corroding and developing excessive frictional resistance. The Fischer & Porter does not use most of these bearings in its design, so it did not develop a stepping problem due to that cause.

The preventive measures consisted of performing a series of "torque tests" on each Leupold & Stevens gage to determine whether the gage exceeded the allowed bearing resistance limits. If the gage failed the torque tests, it was pulled from operation and repaired in the shop by replacing all the bearings, shims, and trip gears. Since the majority of the ADR's used in the CMBP were Leupold & Stevens, the torque tests and refurbishments required large amounts of time, particularly at the beginning, when all Leupold & Stevens gages had to be tested and refurbished if necessary. After a Leupold & Stevens gage was refurbished and placed back into operation, it was torque tested every 6 months unless it was operating in an environment identified as particularly rough on the bearings. Stations exposed to high salinity and/or operating in a small tidal range fell into this category. These stations were torque tested quarterly and the data monitored closely to pick up stepping problems in their early stages.

H. Recommendations

To aid in preventing or preparing for the operational difficulties discussed above, the following recommendations are made.

Large area coverage may or may not be a factor in future programs. If it is, it need not be a problem if adequately handled by good planning. The first step is to realize that the distant tide stations will require more staff hours than others and allow for that in planning the various phases of those tide station's operation and maintenance. The second step is to take added precautions in operating and maintaining those stations. The tide observer takes on added importance. Every effort should be made to find the most competent, reliable individual available, who will faithfully perform his/her duties as a tide observer. In addition to thorough training, the tide observer should be taught to make simple repairs. This is normally not a good idea, but it can result in keeping a data break at these stations within the allowable limits. A temporary repair could enable the tide party to get there before the allowable data break was exceeded. The tide observer should be instructed to attempt these repairs only after discussing the situation by telephone with the tide party. If a gage is nonoperational there is nothing to be lost if the observer cannot effect the repairs.

Special attention should be given to monitoring the data rolls received from these stations to ensure catching mechanical problems at early stages and that the tide observer is performing duties correctly. Additional inspection trips to check the tide gages may also be a prudent measure. The installation of a bubbler backup gage is another precautionary option.

Coping with the environmental problems encountered can be accomplished by good, thorough planning and foresight. When reconnoitering and designing the installation, it should be kept in mind that the site may change drastically under different circumstances such as the freshwater runoff previously discussed. Not every eventuality can be anticipated, but by careful inspection of the area, talking with local residents, and researching any historical information available, a fairly complete picture can be drawn.

Equipment breakdowns are best avoided by routine maintenance, servicing, and by treating the equipment with care. However, breakdowns still occurred due to the extensive use of the equipment. In order to minimize the amount of down time of equipment and its impact on field operations, it would be useful to designate an instrument repairman as a tide party position, similar to the present position at the NOS Marine Centers. In addition to keeping the equipment in good running order, the instrument repairman would perform all shop instrumentation repairs, preventive maintenance, and assist in the fabrication of station components. This would free other personnel to perform their regular duties and cut down on lost time. When possible, the CTP would hire an individual with these qualifications and the improvement in the efficiency of field operations was apparent.

I. Summary

During the 5-year program, 153 tide stations were established with as many as 60 stations operating simultaneously. They were installed, operated, and removed in accordance with NOS standards. Field operations were conducted by the CTP, a combination of Federal and state employees. The tidal datums established, and their preservation through the network of tidal bench marks installed or updated through this program, will benefit the engineer, hydrographer, surveyor, etc., of this and future generations.

IV. DATA PROCESSING AND ANALYSIS Prepared by J. V. Mullin and T. Sheehan

A. Introduction

From 1974 through 1980, the Analysis Branch received 1,512 station months of data from control tide stations and 2,568 station months of data from secondary and tertiary tide stations for processing from the CMBP. When 6-minute records were received for processing and analysis, they were assigned to the west coast team, which only processed tidal data collected on the west coast of the U.S., Alaska, and Hawaii. A description of the processing procedures and the output is described in this section.

B. Processing

The first step in processing is the Comparative Reading at which time one determines a setting and checks the general condition of the data on the record. The staff-to-gage differences are determined by the processor by taking the staff readings as recorded by the observer at the gage and subtracting the actual values recorded on the record at the indicated time. These differences are arithmetically meaned and the average staff-to-gage differences are added to a level constant to provide corrections and continuity with previous records at that station. This will reflect any changes in the staff for the datum of tabulation or station datum to maintain continuity for tidal datums. A setting for the record is then computed. If there are problems with the gage or it has been readjusted, or the staff has been disturbed, a change in the staff-to-gage differences may require a record to be processed on different settings for different time periods. If the gage time differs from the observer's watch time, it is noted so that the time adjustments can be made. Any obviously erroneous staff readings by the observer which do not have any discernible relationship with the other observations are rejected and not included in the computation of the mean.

Problems of erroneous times, heights, or malfunctions in the record are noted on the Comparative Reading to aid in correcting the record while it is being processed. An error code is derived from these trouble-shooting notes to highlight the major problems for future failure analysis. This code is entered into the computer system (First Data) which keeps a record of the status of the gages. To supplement trouble-shooting and to provide "feedback" to the field parties for the repair of malfunctioning gages, an evaluation sheet (Preliminary Evaluation) is prepared for each record. The evaluation sheet summarizes the condition of the gage and is used to tell the tide observer and/or field party the problems which need to be corrected. The main objective is to identify problems quickly so they can be corrected to keep inefficient data to a minimum. After the Comparative Reading is completed, the setting computed, and Preliminary Evaluation filled out, the team leader checks them and sees that the Comparative Reading data with its error code is entered into the computer. The record is then ready for the translation stage which involves the transfer of the 6-minute data from punched paper tapes into computer compatible form. The present procedure is to transfer the data onto a magnetic tape by a digital-to-magnetic tape translator which optically reads the punched paper tape. The magnetic tape containing the 6-minute values is read into the Interdata 7/32 minicomputer. The system is then interrogated through an interactive terminal which has a visual display (cathode ray tube) capability. The record identification number is entered onto the terminal and through the appropriate command, diagnostics are printed out on a printer which is connected to the computer as peripheral equipment. If there are no problems with the data, the tabulated data can be printed out, having the setting applied to the raw value from the record. The tabulation and reduction to means is done automatically by the computer. It is then verified by comparing the results with previous months of tabulations under the direction of a senior oceanographer and the data is ready for datum computations. This represents an ideal situation where there are no defects in the record. When problems are encountered on a less than perfect record, they have to be corrected. Data may contain time problems or invalid punches because of observer problems or gage malfunctions. Troubleshooting records with poor data occurs either at the translation or the edit stage.

The time may be corrected by translating it a few punches ahead (fast) or a few punches behind (slow). Each punch accounts for 6 minutes and times are corrected in 6-minute increments (tenths of hours). Where there are skips or missing punches that do not include a high or low water, linearly interpolated values are entered into the keyboard on the translator. When the results of the processing are checked, one examines the ending time of a unit (string) of data to see if the printed time matches the correct time at the end. The printout of 6-minute values is used as a diagnostic tool to find when and where the time problem occurred.

To check for height discontinuities, the third difference test on the edit routine flags punches which may be erroneous or where especially splashy (high wave action) data occur. A plot may be made on the CRT screen or on a printer to examine suspect data. Where outlier (extreme) points appear to be part of the real tidal phenomenon, they are not altered. If the gage appears to be malfunctioning by a faulty punch, the heights may be corrected by including a "fix" parameter when submitting a job to the computer at the diagnostic scan stage. Where individual values appear to be off, they are corrected on a case by case basis during editing by the operator on a computer terminal connected to the Interdata 7/32 minicomputer. The system allows for breaks in the data to be automatically filled by computer under the control of the analyst. These steps are automatically performed by calling a routine on the computer. However, the tabulations from a comparison station must already be included in the system, with valid data during the break period for comparison purposes. All interpolated and extrapolated values are bracketed to distinguish them from the original data. After records are processed, they are submitted to a team leader to be verified.

The mean values for each month of record are checked against those done previously. If they appear to be in line with past results, the data then enters the datum computation phase of the program.

C. Analysis

There were 2,568 station months of records collected from tide stations established during the CMBP. Incorporated into this number are 193 months of tide records which only have a partial month of high and low waters and hourly heights. Partial months of data result from installing and removing tide gages after the first day of a calendar month. Since it is not always feasible for the field party to install and remove all tide gages on the first day of each month, partial months of records cannot be avoided. The tabulated data from a partial month is considered valid, but no monthly means are determined. Subtracting the 193 partial months of data from the 2,568 months of data received, leaves a total of 2,375 full months of tide data received for processing. Below is a breakdown of the quality, and problems encountered in processing the tide records.

There were 1,675 months of tide record, when after being processed were reduced to a full set of monthly means. The majority of the data was of high quality and required little editing by the analyst. However, a sizeable quantity needed extensive editing and breaks filled to obtain a full tabulated month of data. Problems ranged from minor time adjustments to major mechnical tide gage malfunctions resulting in a complete loss of data.

Efforts were made in the Analysis Branch to provide continuous data from a tide station whenever possible, even if extra editing and/or break filling was required.

There were 69 months of records for which only mean sea level or mean river level were computed. Tide stations located on the Sacramento River, such as Clarksburg (941-5846) or Sacramento (941-6174), had the tidal influence masked by freshwater runoff during portions of the year. In some areas of the Sacramento River, the water levels rose by 10 feet or more during periods of heavy rains. When this occurred, high and low tides could not be tabulated. However, hourly heights could be tabulated and means obtained. When the river levels dropped sufficiently the tidal influence appeared in the records and tides could again be tabulated.

In studies of the lagoons and coastal marshes located near the Mexican border and San Diego, tide gages were installed at the transition zone between the oceanic and estuarine environments. During most of the year, a natural sandbar across the entrance of the estuary prevented the free movement of water into the estuarine system. During these months, tides could not be picked. However, hourly heights were recorded and mean water levels were obtained.

In the Coyote Creek tributary and the Tiajuana estuarine system, 135 months of records had only high waters tabulated. In general, the loss of low waters occurred because the area in which the tide gage was installed went dry at low tide.

There were 212 months of record which had unfilled breaks greater than 3 days and not more than 29 days in length. During these times the tide gage either was inoperative or was recording invalid data, due to observer and/or mechanical problems. The down time can be minimized by having trained tide observers and an adequate number of field personnel who can recognize and correct gage malfunctions.

Substandard data resulted in 65 months of data having to be processed by hand, rather than with the photoelectric scanner. When data was hand processed, only high and low tides were recorded and reduced to monthly means. The hourly heights were not tabulated. The substandard condition can result from either time problems or mechanical problems.

Finally, 219 months of data were classified invalid because of leveling problems or tide gage malfunctions. In some areas of the Sacramento Delta, near the Grant Line Canal, the tide stations worked properly, however, irrigation pumps had been installed in the canals to pump water to the fields. These pumps, when operating, removed vast quantities of water from the canals, which dropped the water level and altered the flow in the canals. Therefore, accurate tidal measurements and datums could not be determined due to the pumping activities in these areas.

The following is a summary of the processing results of the data collected during the CMBP.

Type of Data	Months of Data	Percentage
Partial months of record	193	7%
Complete valid months of data	1,675	65%
Months of data with Mean Sea Level or Mean River Level	69	3%
Months of data with High Waters only	135	5%
Months of data with High and Low Tides only	65	3%
Months of data with breaks greater than 3 days and less than 29 days	212	8%
Months of record with no valid data	219	9%
Total number of months of record received	2,568	100%

V. TIDAL PARAMETERS Prepared by R. A. Smith

A. Introduction

Tidal surveys of the 1970's in California were concentrated in particular regions of the coastal and inland waterways. A majority of the tide gage installations were in the San Francisco Bay Estuarine System. Special regions of tidal studies were Tiajuana Estuary and North San Diego county lagoons in southern California, Elkhorn Slough in central California, and Humboldt Bay along the northern California coast. As never done before on such a large scale, tidal surveys were simultaneously conducted in embayments, sloughs, marsh areas, channels, and rivers. Standard NOS procedures for the computation of the various tidal datums and tidal parameters for the West Coast were followed as outlined in "Tidal Datum Planes (Special Publication 135)" by H. A. Marmer and "Manual of Tide Observations (Publication 30-1)". Regions of high density tidal surveys are listed in Table 1.

Table 1. Tidal Survey Locations

Area	Region	Control Tide Station
Tiajuana Estuary	Southern California	Imperial Beach
Southern Lagoons near San Diego	Southern California	San Diego
Elkhorn Slough	Central California	Monterey
San Francisco Bay Estuarine System	Central California	
Golden Gate	Central California	San Francisco
Northern South San Francisco Bay	Central California	Alameda
Southern South San Francisco Bay	Central California	Alameda San Mateo (West)* Dumbarton Bridge* Coyote Creek*

Area	Region	Control Tide Station
San Pablo Bay Carquinez Strait	Central California	San Francisco
Suisun Bay and vicinity	Central California	Port Chicago
San Joaquin River	Central California	Port Chicago Stockton
Sacramento River	Central California	Port Chicago Stockton
Humboldt Bay	Northern California	Crescent City North Spit

* Secondary Control

B. Tiajuana Estuary

Located due south of Imperial Beach, the most southern town in California and north of the United States-Mexican border, is the Tiajuana Estuary with its inlet exposed to the influence of the Pacific Ocean waters and tides. Oneonta Slough is the major body of water in the estuary with many tributaries contributing to the overall tidal flow in the estuary. The slough bed leading from the ocean through the region is composed of a loose sand base which causes frequent changes in bottom topography. Due to numerous sand spits at the entrance and throughout the slough, the water becomes severely restricted at low water if not completely cut off in parts of the estuary. As a result, "flat low waters" may appear on the tide marigrams. In the computation of tidal parameters in the Tiajuana Estuary, the following results (Table 2) were obtained.

Table 2. Tidal Parameters for Tiajuana Estuary

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-0120	Imperial Beach Ocean	3.74	0.74	0.91	36 Months
941-0013	South Borderfield	1.91	0.69	0.09	3 Months
941-0016	Tiajuana Estuary Entrance	2.20	0.68	0.15	5 Months
941-0020	Oneonta Slough (First Street)	0.88	0.48	0.13	4 Months
941-0023	Sewage Disposal Pond	0.91	0.50	0.11	3 Months
941-0025	Oneonta Slough	0.95	0.41	0.10	3 Months

It was observed that the water level did not fall below a certain level in the various locations occupied in the estuary. Impounding is easily noticed from the tide curve by flat low waters and is termed an "apparent stand at low water." The range of tide is depressed and DLQ is reduced as seen in Table 2. In the upper reaches of the estuary DHQ is reduced due to the restrictions of water flow into this region or trapped water that is unable to return to the ocean because of shifting sand spits in the estuary. A final decision has not been made as to whether all tidal datums will be provided or just high water datums.

C. North San Diego County Lagoons by R. F. Edwing and R. A. Smith

A total of eight tide stations were established in the North San Diego County Lagoon area. Based on the availability of reliable tide records for the region, the following results were obtained (Table 3).

Table 3. Tidal Parameters for North San Diego County Lagoons

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-0396	Oceanside Harbor	3.69	0.71	0.86	8 Months
941-0392*	San Luis Rey River	0.32	0.16	0.07	2 Months
941-0384	Agua Hedionda	3.46	0.80	0.78	7 Months
941-0342	Batiquitos Lagoon East	0.79	0.41	0.06	2 Months
941-0339	Batiquitos	1.94	0.50	0.36	2 Months
941-0302	San Elijo Lagoon	1.38	0.51	0.14	1 Month
941-0299	San Elijo East	1.14	0.44	0.18	1 Month
941-0281	San Deiguito	Obtained water level only			

*Channel shifted leaving gage measuring water level.

Oceanic tidal influence on the lagoons is conveyed through a channel connecting each lagoon to the ocean. The channel, typically comprising only a small percentage of the total lagoon area, is generally the only direct access to the ocean. Thus, large, fast-moving, volumes of water interact through these channels and can quickly erode/deposit large quantities of sediment. As a consequence, the channel is a very transient topographic feature. The tidal heights and times experienced by each lagoon at any one point in time is a direct result of the respective channel's topography at that point in time.

A cyclic nature to the channel's topography became apparent after 1 year's observation of the tides and surrounding environment. The channels alternate between being in erosional and depositional phases. The controlling parameter to these phases is the local seasonal rainfall and weather pattern. In winter, when most of the rainfall occurs, heavy freshwater runoff scours out the channels, widening and deepening them. After the runoff subsides, a deep unobstructed channel allows good tidal interaction between the ocean and the lagoons. However, as the runoff subsides the channels transform from the erosional phase to the depositional phase. The channels slowly silt in, gradually restricting tidal action, until in some cases, the channel is blocked off completely. This situation remains until the onset of the next winter's rains. A rough chronology of the cycle is as follows:

<u>Erosional Phase</u>

1. October - December: The channels are very restricted and may become totally obstructed such that no tidal interaction takes place. The lagoon's water level is very low but rises rapidly as early rains and runoff occur. Some lagoons are drainage basins for creeks, small rivers, and reservoir overflow. The water level can reach an abnormally high elevation.

2. December - April: Heavy rains and runoff scour away the depositional sediment. The channel becomes unobstructed but most tidal influence is masked by the outflow of freshwater runoff from the lagoon. Water level in the lagoon is reduced substantially with much sediment washed down from the drainage basin.

Depositional Phase

1. April - June: The channel is unobstructed and freshwater runoff decreases rapidly. Good tidal interaction occurs with little silting of the channel.

2. June - September: As water levels in the lagoon drop and the outflow velocity of the water decreases, silting increases gradually, restricting the tidal interaction. The channel may begin to close up for short periods and build up towards a permanent obstruction.

All tidal datums are available at Oceanside Harbor and at Agua Hedionda Lagoon (with a qualifying statement). Oceanside Harbor and Agua Hedionda channels were dredged and not subject to the silting obstructions experienced by the other lagoons. Further examination of the tidal observations are needed before any final decision can be made on the other six locations in the area.

D. Elkhorn Slough

After data analysis, one of the four planned secondary stations was redesignated as a tertiary station. Therefore, of the eight stations established, there were three secondary and five tertiary stations. The tidal parameters for Elkhorn Slough, reduced to mean value, for the 1941 through 1959 tidal epoch, are as follows (Table 4):

Table 4. Tidal Parameters for Elkhorn Slough

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-3450	Monterey	3.59	0.71	1.06	19 Months
941-3616	Moss Landing	3.50	0.72	1.03	15 Months
941-3617	Ocean Pier, General Fish Company	3.53	0.70	1.03	4 Months
941-3623	Elkhorn Slough	3.53	0.71	1.04	4 Months
941-3624	Entrance Bridge, Pacific Mariculture	3.61	0.68	1.05	2 Months
941-3626	Elkhorn Yacht Club	3.49	0.70	1.02	4 Months
941-3631	Elkhorn Slough at Elkhorn	3.51	0.71	1.04	15 Months
941-3651	Kirby Park, Elkhorn	3.70	0.69	1.03	4 Months
941-3663	Elkhorn Railroad Bridge	3.71	0.72	1.03	15 Months

There is no apparent restriction of the tidal influence between the ocean water and the sloughs as seen from the results presented above. There were few difficulties in the computation of tidal datums in this region.

E. San Francisco Bay Estuarine System

Most of the tide stations established for the CMBP were in the Bay System. Tidal observations were made at all but a few of the 1930 sites and some new locations were added during the boundary program. The Bay system has been broken down into the following areas for the convenience of discussion:

1. Golden Gate
2. San Francisco Bay
3. San Pablo Bay and Tributaries
4. Carquinez Strait
5. Suisun Bay and Vicinity
6. San Joaquin River
7. Sacramento River and Delta Area

1. Golden Gate

All ocean waters that enter the San Francisco Bay Estuarine System do so through the Golden Gate. The tidal characteristics at the Gate are changed only slightly from those on the ocean as the ocean waters enter the Bay. The following tidal parameters were computed at the Golden Gate (Table 5) using the tidal observations collected during the boundary program.

Table 5. Tidal Parameters for Golden Gate

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-4906	Bonita Cove	4.20	0.55	1.17	2 months
941-4290	San Francisco	3.99	0.60	1.12	19 years
941-4806	Sausalito	3.84	0.59	1.12	24 months
941-4818	Angel Island	4.08	0.58	1.15	9 months

2. San Francisco Bay

Over the duration of the program a high concentration of tide stations were in operation on the west side of south San Francisco Bay, both within the sloughs and within the Bay proper. Only a few locations were occupied south of Oakland on the east side of the Bay. This was primarily because of the extensive mud flats and it was difficult to establish stations that could be properly attended. The mean range of tide increases from north to south in the Bay, with the range accounting for a large percentage of the Bay volume, because the tidal range is large relative to the average water depth. The value of DHQ is virtually the same (0.6 foot) throughout the Bay while DLQ increases 0.1 foot from 1.1 to 1.2 feet north to south along the perimeter of the Bay (table 6).

Table 6. Tidal Parameters for San Francisco Bay (Proper)

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-4305	North Point	4.23	0.60	1.09	17 Months
941-4317	Pier 22-1/2 San Francisco	4.44	0.61	1.08	17 Months

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-4358	Hunters Point	4.90	0.60	1.11	13 Months
941-4391	South San Francisco	5.22	0.61	1.12	9 Months
941-4413	Seaplane Harbor	5.36	0.63	1.15	5 Months
941-4449	Coyote Point Marina	5.53	0.61	1.15	12 Months
941-4458	San Mateo Bridge (West)	5.75	0.62	1.16	24 Months
941-4501	Redwood Creek (CM8)	6.07	0.61	1.20	21 Months
941-4509	Dumbarton Bridge	6.48	0.60	1.20	21 Months
941-4575	Coyote Creek Entrance	7.04	0.60	1.26	13 Months
941-4609	South Bay Wreck	6.16	0.61	1.19	11 Months
941-4637	San Mateo Bridge (East)	5.83	0.62	1.15	3 Months
941-4688	San Leandro Channel	5.47	0.62	1.15	19 Months
941-4750	Alameda	4.70	0.61	1.12	19 Years
941-4779	Matson Wharf (Oakland)	4.38	0.60	1.09	15 Months
941-4816	Berkeley	4.29	0.59	1.12	6 Months
941-4849	Richmond (Inner Harbor)	4.15	0.59	1.10	12 Months
941-4881	Point Orient	4.14	0.59	1.09	24 Months
941-4873	Point San Quentin	4.01	0.59	1.06	20 Months
941-4837	Point Chauncey	3.94	0.59	1.07	9 Months

In South San Francisco Bay there are many creeks and sloughs off the mainstream of the Bay. The tidal influence is restricted in some of the sloughs (Table 7). Such occurrences are due to restrictions within the region such as the topography or depth of channel at low water stages. In a few instances, only the high water datums were computed. In other cases, the DLQ was reduced and the mean range of tide depressed as shown in Table 7.

Table 7. Tidal Parameters for San Francisco Bay (Slough Regions)

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-4483	Bay Slough (West)	5.85	0.62	1.12	8 Months
941-4486*	Bay Slough (East)	5.72	0.62	0.85	6 Months
941-4505	Corkscrew Slough	6.24	0.63	1.15	7 Months
941-4506	Newark Slough	6.65	0.59	1.18	4 Months
941-4507	Westpoint Slough	6.25	0.63	1.16	8 Months
941-4513	Granite Rock	6.19	0.61	1.17	8 Months
941-4519	Mowry Slough	6.70	0.56	1.12	6 Months
941-4521*	Mud Slough	6.43	0.59	0.46	4 Months
941-4537*	Palo Alto (CM #8)	high water only			24 Months
941-4548*	Guadalupe Slough	high water only			16 Months
941-4549	Upper Guadalupe Slough	7.32	0.61	1.27	2 Months
941-4551	Gold Street Bridge	7.38	0.61	1.21	5 Months
941-4561*	Coyote Creek Tributary 1	7.04	0.58	0.79	5 Months
941-4589*	Coyote Creek Tributary 2	high water only			4 Months
941-4585*	Coyote Creek Tributary 3	high water only			5 Months
941-4621*	Coyote Hills Slough	5.57	0.60	0.51	4 Months
941-4632*	Alameda Creek	5.17	0.59	0.30	3 Months
941-4711	Oakland Airport	4.87	0.62	1.09	5 Months
941-4746	Park Street Bridge (Oakland)	4.66	0.62	1.11	5 Months
941-4764	Oakland Inner Harbor	4.59	0.61	1.12	5 Months

* Restricted Tides

3. San Pablo Bay and Tributaries

The mean range of tide in San Pablo Bay is greater than the Golden Gate region and increases in the upper reaches of the tributaries branching out from the Bay. The values of DHQ and DLQ are 0.1 to 0.2 foot less than at the Golden Gate (Table 8). The San Pablo Bay tidal regime is influenced by the waters from the ocean and river discharge from the San Joaquin, and the Sacramento River through Carquinez Strait.

Table 8. Tidal Parameters for San Pablo Bay and Tributaries

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-5056	Pinole Point	4.27	0.58	1.03	17 Months
941-5074	Hercules	4.16	0.57	0.91	12 Months
941-5338	Sonoma Creek Entrance	4.19	0.55	0.85	12 Months
941-5447	Sonoma Creek (Wingo)	4.38	0.54	0.82	3 Months
941-5252	Petaluma River Entrance	4.37	0.57	0.99	22 Months
941-5423	Lakeville, Petaluma River	4.76	0.50	0.91	12 Months
941-5584	Upper Drawbridge (Petaluma Creek)	5.00	0.49	0.91	12 Months

4. Carquinez Strait

Carquinez Strait is the connecting waterway between San Pablo and Suisun Bay. The Strait is a deep channel that maintains its depth by the strong tidal currents that flow through the channel. The mean range of tide decreases from west to east in the Strait with no appreciable change in DHQ and 0.1 foot decrease in DLQ from west to east. Table 9 is a summary of the data collected for Carquinez Strait.

Table 9. Tidal Parameters for Carquinez Strait

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-5218	Mare Island Navy Yard	4.01	0.56	0.92	16 Months
941-5143	Crockett	4.04	0.54	0.93	14 Months
941-5111	Benicia	3.62	0.51	0.81	36 Months
941-5103	Suisun Point	3.70	0.50	0.80	3 Months

5. Suisun Bay and Tributaries

Suisun Bay is a broad, shallow body of water with many marshes and numerous islands. Considerable quantities of fresh water are continually discharged into Suisun Bay by the Sacramento and San Joaquin Rivers. This fresh water has a considerable influence on the tidal characteristics in this locality. In the Suisun sloughs DHQ and DLQ are consistently between 0.5 and 0.7 foot, respectively. In Suisun Bay the DHQ and DLQ is 0.5 and 0.6 foot, respectively. The mean range of tide is less in the bay than in the adjoining sloughs with the range of tide increasing in the upper reaches of the sloughs, which is similar to the situation that occurs in San Pablo Bay. The tidal parameters computed for this area are listed in Table 10.

Table 10. Tidal Parameters for Suisun Bay and Tributaries

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-5266	Pierce Harbor, Goodyear Slough	3.43	0.47	0.66	12 Months
941-5498	Suisun Slough Entrance	3.40	0.49	0.68	15 Months
941-5379	Joice Island, Suisun Slough	3.66	0.48	0.69	15 Months
941-5265	Suisun City, Suisun Slough	3.84	0.47	0.68	12 Months
941-5402	Montezuma Slough Bridge	3.58	0.49	0.69	12 Months
941-5307	Meins Landing, Montezuma Slough	3.56	0.49	0.68	12 Months
941-5144	Port Chicago, Suisun Bay	3.37	0.49	0.69	24 Months
941-5112	Mallard Ferry Wharf, Suisun Bay	2.89	0.48	0.59	15 Months
941-5096	Pittsburg, New York Slough	2.90	0.49	0.60	5 Months

6. San Joaquin River

The San Joaquin River is a meandering narrow body of water with many tributaries off the main stream and also connecting with the Sacramento River. In this region DHQ and DLQ are consistently about 0.45 foot with the mean range of tide between 2.3 and 2.7 feet in the various segments of the river system. Table 11 is the result of data collected during the boundary program.

Table 11. Tidal Parameters for the San Joaquin River

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-5063	Antioch	2.68	0.46	0.57	24 Months
941-5145	False River	2.31	0.43	0.47	16 Months
941-5193	Three Mile Slough	2.26	0.44	0.46	12 Months
941-5198	Potato Slough	2.47	0.42	0.48	5 Months
941-4868	Orwood	2.37	0.41	0.44	12 Months
941-5149	Prisoner's Point	2.40	0.42	0.44	19 Months
941-5105	Wards Cut	2.50	0.42	0.45	15 Months
941-4866	Holt, Whiskey Slough	2.66	0.44	0.45	15 Months
941-5021	Black Slough Landing	2.71	0.44	0.45	12 Months
941-5004	Eldorado Pump	2.78	0.43	0.44	4 Months
941-4883	Stockton	2.85	0.43	0.44	12 Months
941-4867	Borden Highway Bridge	2.26	0.44	0.46	12 Months

7. Sacramento River and Delta Area

In the lower reaches of the Sacramento River, the mean range of tide increases from 2.8 to 3.1 feet from the entrance up the river, and the DHQ and DLQ are generally 0.5 to 0.6 foot, respectively. In the mid-reaches of the river, the range of tide is depressed at high water stages in the winter and spring and the tidal action is restricted. In the upper reaches of the river, tidal influence generally diminishes in the vicinity of Knights Landing (941-6643) where the tide is apparently completely masked by river discharge. Table 12 lists the results of tide observations collected in the river during the boundary program.

Table 12. Tidal Parameters for Sacramento River

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-5176	Collinsville	2.79	0.47	0.58	15 Months
941-5236	Three-Mile Slough	3.01	0.46	0.58	16 Months
941-5316	Rio Vista	3.12	0.47	0.57	14 Months
941-5257	Terminous	2.52	0.43	0.43	12 Months
941-5478	New Hope Bridge	2.22	0.42	0.34	12 Months
941-5489*	Walnut Grove	2.16	0.40	0.29	13 Months
941-5522*	Benson Ferry Bridge	2.07	0.40	0.32	12 Months
941-5565	Snodgrass Slough	1.83	0.36	0.29	12 Months
941-5846*	Clarksburg	1.37	0.39	0.18	8 Months
941-6174*	Sacramento	0.83	0.30	0.13	9 Months
941-6643**	Knights Landing	-	-	-	9 Months

* Tidal Influence Significantly Masked Periodically by River Discharge
** Beyond Tidal Influence

The Delta area is southeast of the San Joaquin River and south of the Sacramento River. It is characterized by the many interconnecting channels or tributaries, such as Old River, Middle River, and extensions of the San Joaquin River. The tidal conditions in some regions of the Delta were affected by freshwater runoff or by water being pumped out of the tributaries for irrigation purposes. Table 13 shows the locations where data was collected in the Delta Area during the boundary program.

Table 13. Tidal Parameters for Lower Delta Region

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-4794*	Clifton Court, Old River	--	-	-	17 Months
941-4785*	Grant Line Bridge, Old River	--	-	-	5 Months
941-4778*	Naglee Bridge, Old River	--	-	-	5 Months
941-4759*	Holly Sugar Refinery, Old River	--	-	-	5 Months
941-4768**	Mossdale Bridge	1.19	0.35	0.18	5 Months

* Tide affected by daily pumping of water from Old River for irrigation of the Delta region.
** Subject to freshwater runoff that masks the tide.

F. Humboldt Bay

There were only two stations installed between San Francisco and Humboldt Bay during the CMBP. They were at Point Reyes and Arena Cove, which have become part of the NTON. There are few areas along this portion of the California coast where tide gage installations are possible because of the rugged coastal terrain.

In lower Humboldt Bay the tidal parameters are relatively constant with the mean range of tide between 4.8 and 4.9 feet and DHQ at 0.7 foot and DLQ at 1.2 feet. In the upper Bay, north of the inlet, the situation is different. From the inlet up through to the entrance to Mad River and over to Eureka, the range of tide increases with DHQ and DLQ remaining unchanged at 0.7 and 1.2, respectively; except in the Elk River and slough regions, east of Eureka. The tidal parameters based on the 1970's surveys are given in Table 14.

Table 14. Tidal Parameters for Humboldt Bay

Station Number	Station Name	Mn	DHQ	DLQ	Series
941-8686	Hookton Slough	4.92	0.71	1.19	12 Months
941-8723	Fields Landing	4.82	0.71	1.20	9 Months
941-8739	Red Bluff Bridge	4.81	0.71	1.18	9 Months
941-8757*	Elk River	3.94	0.72	0.38	11 Months
941-8767	North Spit	4.82	0.71	1.20	12 Months
941-8778	Bucksport	4.93	0.71	1.25	6 Months
941-8801	Eureka	5.23	0.72	1.24	25 Months
941-8817	Samoa	5.24	0.72	1.24	9 Months
941-8799	Freshwater Slough	5.30	0.72	1.06	7 Months
941-8802	Eureka Slough	5.38	0.73	1.24	7 Months
941-8865	Mad River	5.60	0.72	1.29	22 Months
941-8983	Upper Mad River	4.77	0.68	1.17	5 Months

* Reduced Range and DLQ due to Topography of River

G. Comparison of Tidal Characteristics

Several stations along the California coast have sufficient data to compare mean range over a 57-year period or three tidal epochs. In general, the data indicates little change in range at most stations, except at Benecia and Eureka. The following is a summary of the mean range (in feet) compared at selected locations over three tidal epochs.

	Tidal Epoch		
	1924-1942	1941-1959	1960-1978
San Diego	4.1	4.1	4.1
Los Angeles	3.8	3.8	3.8
San Francisco	4.0	4.0	4.1
Sausalito	3.9	3.9	4.0
Benicia	4.1	4.3	3.7
Eureka	5.0	5.2	5.3
Crescent City	5.1	5.1	5.1

Data collected from this program and prior surveys provide an opportunity to compare tidal datums (1941 to 1959 tide epoch) at specific locations relative to the National Geodetic Vertical Datum (NGVD). Figure 6 shows the relative changes between this program and prior surveys.

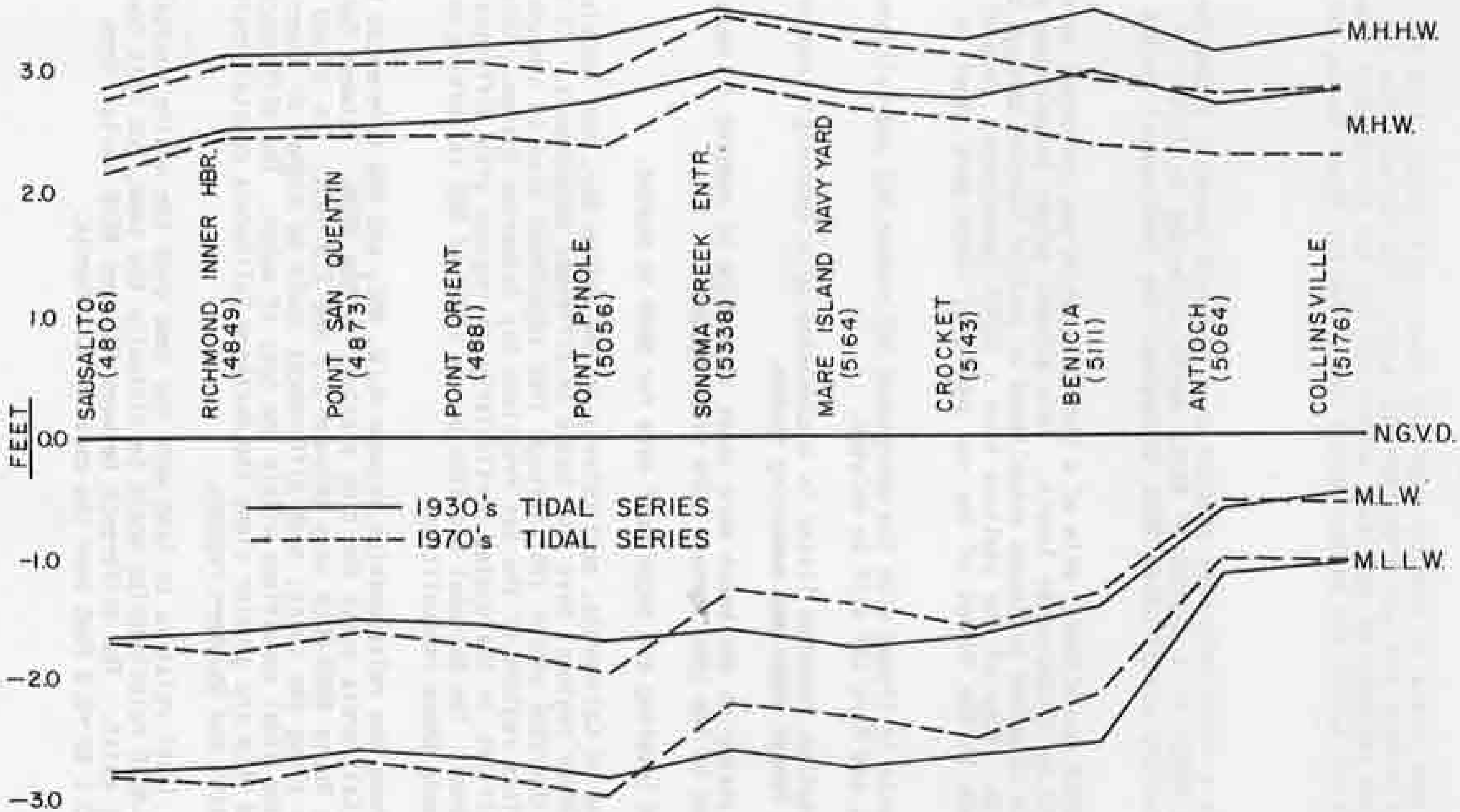


FIG. 6: TIDAL DATUMS RELATIVE TO N.G.V.D. BETWEEN 1930's AND 1970's TIDAL SERIES IN SAN FRANCISCO BAY ESTUARINE SYSTEM

DRAWN RJM

Figure 7 shows plots of monthly mean sea level data during 1978 for several stations within the San Francisco Bay area. The curves show the relatively uniform response of sea level within the Bay and the general trend of a high sea level during the winter months and a low sea level during the summer months.

H. NGVD

The NGVD is a fixed reference adopted as a standard geodetic datum for elevation. The NGVCN is a system of bench marks connected by first- or second-order leveling establishing NGVD throughout the continental United States.

When the NGVCN was within 1 mile of a tide station it was connected to the tidal bench marks by second-order levels. This allowed datums established at one station to be compared to datums established at another station through the NGVD relationship. Many of the stations have a NGVCN connection. Several changes were made in the format of the new published bench mark sheet as follows:

1. California is listed with the designated NOS number 941 and California Part I, Part II, and Part III will be deleted.

2. Each station location listed is accompanied by a four-digit number rather than the former index map numbering system.

3. It is stated on the bench mark sheet that MLLW is reduced to mean values referenced to the 1960 through 1978 tidal epoch.

4. The NOS leveling and adjustment date for NGVD is stated.

Most regions in California, particularly in the Suisun Bay, San Joaquin, and Sacramento River regions, have NGVD based on different adjustments. It is common to find the 1956 and/or 1967 through 1968 adjustment used to compute NGVD in the various regions of the San Francisco Bay Estuarine System. This leads to inequalities in the system particularly in regions with different rates of subsidence. The National Geodetic Survey (NGS) of NOS is working on a system to eliminate these inequalities.

Figure 8 shows the relationships between MLLW, MSL, and MHW referenced to NGVD along the California coast for tide stations in the NTON. Between San Diego and Point Reyes NGVD-MLLW vary between 2.5 and 2.9 feet. In inland bodies of water along the coast, such differences could be higher or lower depending upon the tidal conditions within the body of water. The differences between NGVD and MLLW are greater along the Northern California coastal region compared to Central and Southern regions.

If the sea level relative to land were the same over the entire coastal region, the MSL-NGVD relationships would be virtually the same, but this condition does not exist. The difference between MSL and NGVD varies from approximately -0.1 to +0.3 foot over the coast of California.

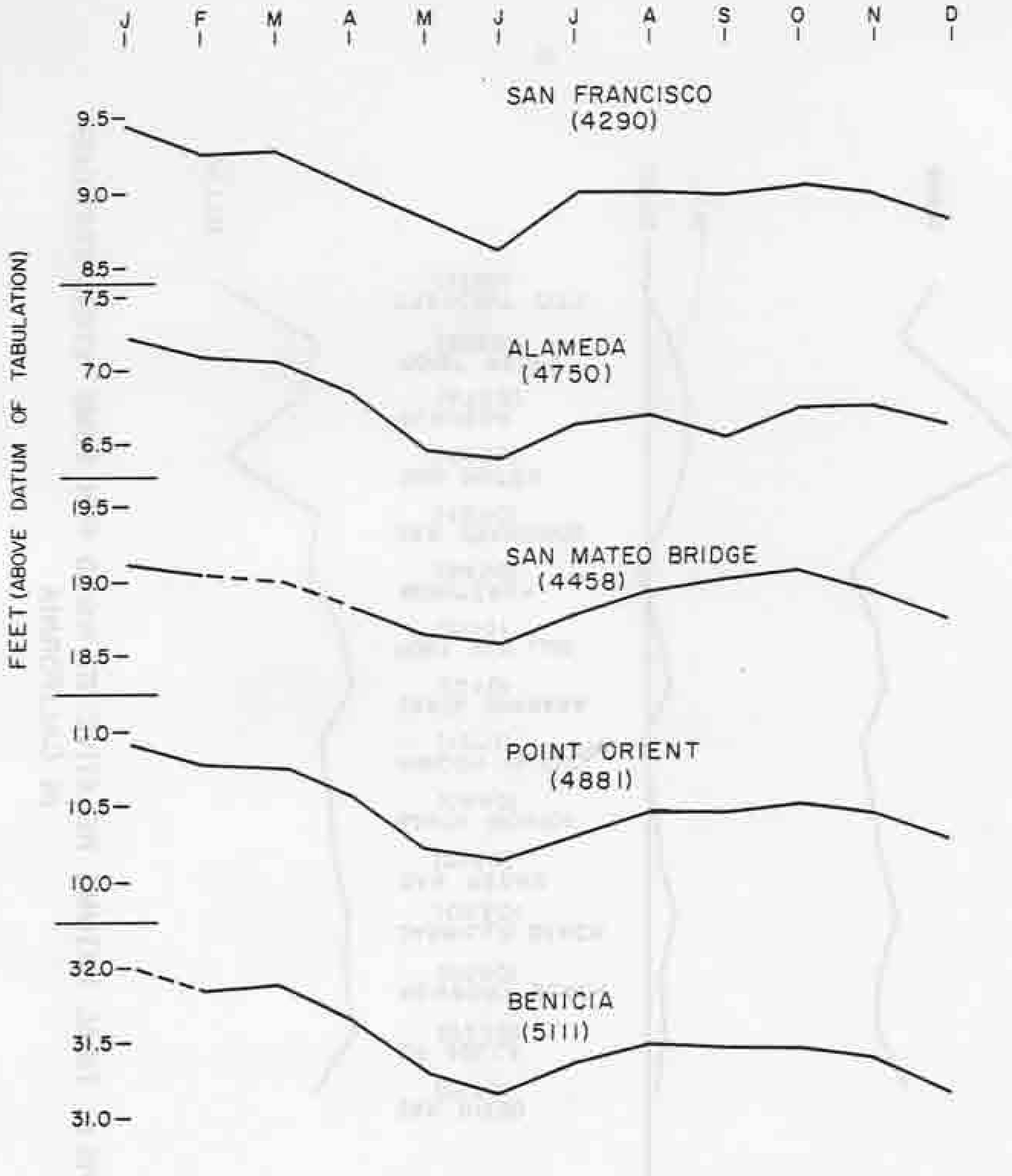


FIG. 7 MONTHLY MEAN SEA LEVEL IN SAN FRANCISCO BAY FOR 1978

DRAWN RJM

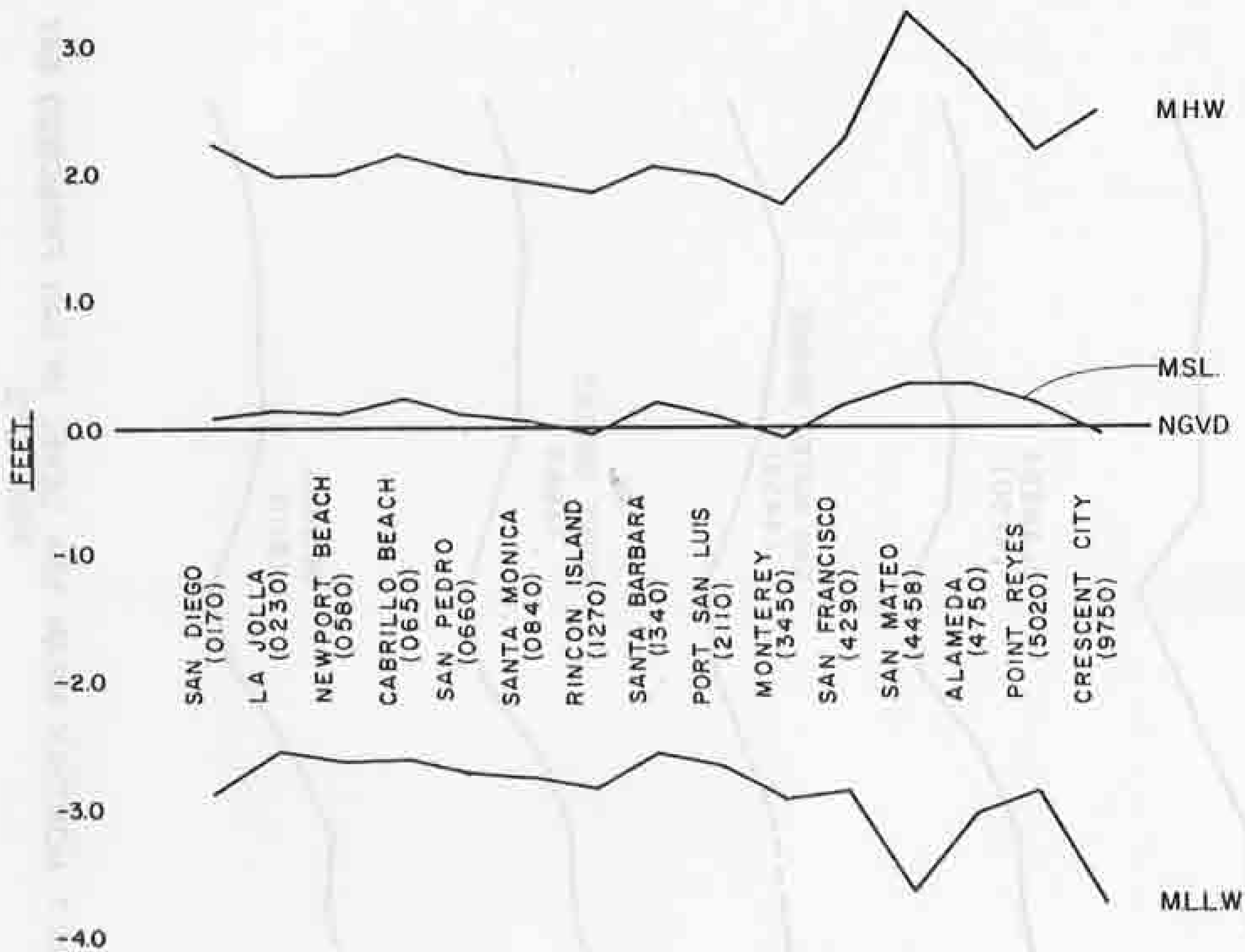


FIG. 8: TIDAL DATUMS RELATIVE TO N.G.V.D. FOR SOME N.T.O.N. STATIONS IN CALIFORNIA

DRAWN RJM

The difference between MHW and NGVD varies from 1.8 to 2.2 feet between San Diego and Point Reyes. Such differences are higher in Northern California. Again with MHW-NGVD as with NGVD-MLLW such differences can be greater or less along the coastal region than inland bodies of water, depending upon the range of tide, other tidal conditions, and topography.

The NOS presently has published NGVD-MLLW information for California with station locations originally occupied in the 1930's. Most of these sites were reoccupied during the CMBP. Since there is evidence of subsidence in parts of California, for example, the Suisun Bay, San Joaquin and Sacramento Rivers regions, NGVD-MLLW will not be published for all reoccupied sites where NGVD-MLLW were formerly published. However, NGVD-MLLW can be provided on a continual basis for those sites where subsidence is occurring with the understanding that there is a reduced accuracy in the NGVD-MLLW values and caution should be taken in the use of data from such locations.

VI. PROGRAM ACCOMPLISHMENTS

A. Introduction

The program accomplishments listed here represent targeted goals directly attained by the NOS/CMBP within a specific time period. What cannot be fully listed are the many benefits and long-range uses that the tidal network established by the program can provide. Federal, state, and private sectors will utilize the network and tidal data for decades to come, for delineating boundaries, mapping coastal areas, construction, scientific research, and managing coastal resources.

The 304 tide stations originally proposed were the optimum number planned to fulfill all possible NOS/State of California requirements. Approximately 50 percent (153 stations) of the proposed network was established, with budgetary and operational restraints preventing full completion. These stations were established in high priority areas as jointly determined by NOS and the State of California.

B. Tide Stations

The program originally required four new primary tide stations in addition to the existing NTON stations. Primaries were established at Port Chicago, Suisun Bay, and San Mateo, South San Francisco Bay. Two future primary stations will be selected from three, currently operating, long-term secondary stations. North Spit, Humboldt Bay, is one and the other is to be determined by data evaluation and other requirements from stations operating at Sacramento and Stockton.

Eighty (70 percent) of the planned 114 secondary stations, and 71 (38 percent) of the planned 186 tertiary stations were established during the program. The tertiaries were operated in conjunction with their controlling secondaries as required.

The following table provides a summary of the number of stations established in various geographic locations:

Geographic Location	Primary	Secondary	Tertiary	Total
Tiajuana Estuary		3	2	5
San Diego County Lagoons		9	0	9
Moss Landing		4	4	8
South San Francisco Bay	1	11	20	32
North San Francisco Bay		7	12	19
Tomales Bay		0	3	3
San Pablo Bay		9	5	14
Suisun Bay	1	6	8	15
Delta Region		27	9	36
Humboldt Bay	–	4	8	12
Total	2	80	71	153

In addition to the planned activities a special project was undertaken which required a 6-month extension of the program from December 1979 to June 1980. This project involved a study of the Sacramento River and some coastal marshes and lagoons in Southern California.

C. Tidal Bench Marks

An essential part of the establishment of a tide station is the installation and leveling of a system of tidal bench marks to which tidal datums are ultimately referenced. These bench marks provide a permanent record and method of recovering tidal datums long after the actual tide station has been removed. The datums computed for each bench mark are periodically updated using data from the 20 control tide stations currently in operation. As a result of the program, approximately 950 permanent tidal bench marks were established or updated.

As a rule, if a tide station is within 1 mile of the NGVCN, a level connection is made to establish the relationship between the local tidal datums and NGVD. This allows datums established at one tide station to be compared to datums established at other tide stations through the NGVD relationship. Most stations established during the program were connected to NGVD. Those stations not connected were generally too far from the NGVCN.

D. Tidal Datums

The tidal datums established at each tide station are the principal product published and provided by NOS to the user. Datums can be transferred through surveying and utilized in engineering, charting, scientific, and legal applications.

Of the 2,375 stations months of data collected, 2,156 stations months, or 90 percent, were processed and found acceptable for computing tidal datums. Presently, datums have been published for 105 of 153 station locations established (69 percent completed). The remaining station locations will be published by the end of Fiscal Year 1983, except for several of the San Diego County Lagoon and a few Sacramento River stations. These stations do not exhibit periodic tidal fluctuations (due to freshwater influx, excessive pumping activities, etc.), therefore, conventional tidal datums cannot be computed.

E. Bench Mark Publications

The tide stations at Imperial Beach (941-0120), Cabrillo Beach (941-0650), and Santa Barbara (941-1340) have been removed, but plans are to update the bench mark publications to the revised format and elevations of bench marks referred to the 1960-78 tidal epoch. Historical stations at Holly Sugar Refinery (941-4759), Naglee Bridge (941-4778), Clifton Court (941-4794), and Grant Line Bridge (941-4785) were reoccupied, but no bench mark sheets will be published because of the daily extraction of water by irrigation pumps. Other historical tide stations, Selby (941-5142), Frank's Tract (941-5095), Union Island Highway Bridge (941-4827), Jacobs Road (941-4882), Webb Ferry (941-5147), Junction Old and San Joaquin River (941-4781), Carquinez Strait Lighthouse and Vicinity (941-5166), Tubbs Island Wharf (941-5356), South Pacific Railroad, Dumbarton Point (941-4510), and Alameda Electric Light Plant (941-4756), were not reoccupied and have been dropped from the published list. The historical stations not reoccupied but retained are Point Isabel (941-4843) and Angel Island, West Garrison (941-4817). The tide station at South Bay Wreck (941-4609) has tidal datums but no bench marks established. Tidal datums cannot be computed for Knights Landing, Sacramento River, because of the high river staging masking the tide; therefore, no published sheet will be available for this location. Many of the bench mark sheets for locations listed in California Part I and Part II were dropped from the published list. This was because of either insufficient length of series, lack of adequate 19 year control, or evidence of bench mark instability. If a tide station has less than three recoverable bench marks and the differential elevations change significantly, the tidal bench mark sheet also would be dropped from publication. However, the information would be kept on file and provided to the public upon request.

F. Index Maps

Users of the products provided by the program, will be informed of the data available by two sets of index maps, now available. One set of charts shows the locations for all tide stations in the state for which bench mark sheets are published. The second set of charts shows all station locations where tidal observations were made. To supplement the index maps, a station list will be provided giving the station number, name, geographic position, installation and removal dates, bench mark publication date, and length of series used for computing the published datum.

The index maps will be maintained and updated at NOS Headquarters in Rockville, Maryland. Distribution of the index maps to the user will be handled jointly by the NOS and the State Lands Division. Details for requesting maps will be published in appropriate professional journals.

VII. RECOMMENDATIONS

A. Introduction

This section is based upon experiences and information derived not only from the CMBP, but also from NOS involvement in other state cooperative programs. Recommendations are made on preserving past program's accomplishments, on updating them, and on conducting future tidal surveys.

B. Bench Mark Maintenance

Each tide station established during the program had a minimum of five bench marks installed and/or recovered. Periodic maintenance of the bench marks is essential to the preservation of the tidal datums established. The bench marks are the only means of recovering the datums at the station once the instrumentation has been removed, other than through the complete reinstallation of the station. If the number of bench marks at a station drops to two or less, then the datums are potentially lost, unless the difference in elevation between the two bench marks has remained constant. Even with two marks, the credibility of the datums is questionable, since local movement could affect the elevation of both marks equally.

A bench mark maintenance program would consist of periodic inspections of each station location involving recovery of the bench marks, stability levels, updating descriptions, and possibly the collection of additional tide data. If any bench marks have been destroyed or show excess movement, they should be replaced. A program of this nature is currently being implemented in Florida and New Jersey.

C. Future Tidal Surveys

Some areas of the state were surveyed much more intensively than others due to pending litigation and other Federal/State requirements. Budgetary and operational restraints prevented planned lower priority stations in other areas from being established. Thus, only limited data is available from certain coastal regions, particularly between Port San Luis and San Francisco (except Monterey Bay), and between Arena Cove and Humboldt Bay. These areas should be included in any future tidal survey.

Future tidal programs also should resurvey the region between the Carquinez Strait and the San Joaquin-Sacramento River systems. The tidal characteristics in this region, coupled with subsidence, have changed drastically. This transition is an ongoing process and needs to be monitored closely.

D. NGVCN

At stations where the CMBP did not determine rates of subsidence, only conditional NGVD-MLLW values are provided. These values will not be published, but can be provided to the State of California, State Lands Commission upon request. Releveling of the NGVD network in some areas will be required to detect and measure such movements. It is recommended that a joint program between NOS and the State be established to relevel the NGVD network in these areas.

E. Integrated Logistics Support (ILS)

NOS has developed and adopted a systematic standardized approach for the tidal support of its water levels measurement system, called ILS. In addition to documenting operational and maintenance procedures, it involves modification of ADR tide gages to reduce gage down time and thus data loss. It is recommended that any future tidal survey be performed in accordance with ILS standards to increase the efficiency of the operation and produce high quality data.